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EVALUATION OF ORTHOSTATIC TOLERANCE

(Zur Beurteilung der orthostatischen Toleranz)

## Zur Beuteilung der orthostatischen Toleranz

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### Today's Significance of the Schellong Test

One of the most important regulation tests in use is the so-called Schellong orthostatic test for determining circulatory behavior in a person upon changing position. The test procedure is first to measure the circulatory factors, pulse rate ( $f$ ), systolic blood pressure ( $RR_2$ ), and diastolic blood pressure ( $RR_d$ ), with the patient lying down. The patient then is brought upright, either actively, or passively using a tilt table. The orthostatic test then is conducted by measuring circulatory factors every minute, and these then are correlated with the values obtained lying down. Appropriate conclusions as to circulation regulation are drawn from changes in pulse rate and blood pressure values, as well as from the behavior of blood pressure amplitude in accordance with criteria established by Schellong, Lüdertitz, Schmidt-Voigt, and other authors. The original Schellong method, designed to derive so-called normal behavior from a hypotonic, or hypodynamic, disturbance in circulatory regulation, has been abandoned since it has been found that both regulation mechanisms are to some degree dependent on age, and that it is impossible to draw far-reaching conclusions about circulation from blood pressure, although blood pressure is known to be essentially a function of peripheral and elastic vascular resistance. Today, orthostatically labile and insufficient circulation (Schmidt-Voigt, Brehm and Wezler, Kirchoff) are more readily differentiated on the basis of the behavior of pulse rate and of blood pressure in the orthostatic test as compared to changes in the same circulatory factors in the horizontal position.

### Preliminary Remarks Concerning Physical Concepts

Let us present a few preliminary remarks about physical concepts to show how the effect of the hydrostatic laws of physics becomes apparent in the characteristic behavior of these circulatory factors when the body is moved from a horizontal to a vertical position, before we discuss the evaluation criteria of pulse rate and blood pressure in the orthostatic test.

The circulatory factors under discussion change as soon as a person in a resting state is brought from a horizontal to a vertical position. The pulse rate will generally increase significantly, and there will be something of a drop in systolic blood pressure. Diastolic blood pressure, on the

other hand, will increase. The result is a lesser blood pressure amplitude, which, as we know, is the difference between the systolic and the diastolic pressures. The increase in diastolic pressure, which should be equated to vascular pressure, means that the weight of the "column of blood" is added when upright; expressed physically, the percentage of hemostatic pressure. We speak of hydrostatic pressure in connection with a column of water, but in our case the term "hemostatic pressure" is more suitable. The increase in diastolic pressure can be equated to the weight of the column of blood consisting of that of the upper arm - head, because systolic, as well as diastolic, pressure is measured at the upper arm by the conventional Riva-Rocci method. A correspondingly higher hemostatic pressure would result if the measurement were made at the lower leg.

The height of the hemostatic head,  $h$ , is calculated by using the formula

$$h = \Delta p / \rho \text{ blood} \quad (1)$$

where  $\Delta p$  is the pressure difference between the vertical and horizontal positions, and  $\rho$  is blood density ( $\rho \text{ blood} = 1.06 \text{ g}$ ). It is interesting to note that the cross section plays no part in the calculation of the height of the hemostatic head, and this is known from hydrostatic tests with vessels of various shapes. Hydrostatic pressure is solely dependent on the liquid column and the density of the liquid. The width of blood vessels therefore can be neglected. If we convert the pressure difference from mm Hg to g/unit area ( $1 \text{ mm Hg} = 1.36 \text{ g/cm}^2$ ), and use a blood density of  $1.06 \text{ g}$ , the height of the hemostatic head, in cm, is

$$h = 1.28 \Delta RR_2 \text{ (mm Hg)} \quad (2)$$

The mean difference in diastolic pressures in the horizontal and upright positions was  $7.82 \text{ mm}$  for 500 healthy military personnel of all age groups. This yielded a height of  $10.0 \pm 5.9 \text{ cm}$  when multiplied by  $1.28$  (the conversion factor for mm Hg to g: blood density). The mean blood column is  $10 \text{ cm}$  from the upper arm cuff upward, when the person tested is standing. If we take into consideration the fact that only about 10-20% of the blood is lifted to the upper vessel sections, it becomes understandable that this height, with a maximum deviation of about  $6 \text{ cm}$ , is relatively small compared to the real upper arm-head distance.

Performance can be calculated from the behavior of pulse rate and blood pressure in the horizontal and vertical positions and the corresponding values provide something of an insight into the relationships that exist between the major circulatory magnitudes. Among the most important circulatory factors are:

1. pulse rate ( $f$ );
2. blood pressure ( $RR_s$ );
3. stroke volume ( $V_s$ ).



Dimensional "performance" can be derived by calculating the product of these different factors, because pressure has the dimension of a force/cm<sup>2</sup>, stroke volume has the dimension of cm<sup>3</sup>, and pulse rate that of liter/sec. Accordingly, by multiplying  $f$ ,  $RR_s$ , and  $V_s$ , we obtain, as a dimension,

$$\text{force} \cdot \frac{\text{cm}}{\text{sec}} = \frac{\text{work}}{\text{sec}} = \text{performance}.$$

Blood, as it circulates through the body, which is a closed system, must perform work to overcome friction along the vascular walls and in the capillaries in every position, even the vertical, and the performance of this work includes consumption of the energy of the nonlaminar blood flow, so the work performed by the body per second in the horizontal position can be equated to the work performed in the same time period in the vertical position, if the energy consumed in overcoming friction losses is considered to be equal in both positions, and if the body remains in a resting state, and is not under stress in either position.

Designating the systolic pressures in the horizontal and vertical position  $RR_{sh}$  and  $RR_{sv}$ , stroke volumes in these positions  $V_h$  and  $V_v$ , and the corresponding pulse rates  $f_h$  and  $f_v$ , we obtain

$$RR_{sh} \cdot V_h \cdot f_h \approx RR_{sv} \cdot V_v \cdot f_v \quad (3)$$

Note the interesting fact that the product remains approximately constant, whereas the circulatory factors, as is known, change in size.

Systolic blood pressure drops in the vertical position, but the increase in pulse rate, in percent, is greater than the increase in pressure (symbolized in the equation by appropriate arrows). The reason for these opposite behaviors can only be attributed to the corresponding decrease in stroke volume. Yet another reason for the drop in systolic pressure undoubtedly is associated with the increase in diastolic pressure. Therefore,  $RR_{sv}$  must be corrected by the hemostatic pressure difference,  $\Delta RR_d$ , in Eq. (2) so as to eliminate the effect of hemostatics. This is necessary from the physical-mathematical standpoint, in order to obtain the correct stroke volume relationship between the horizontal and upright positions. Therefore,

$$RR_{sh} \cdot V_h \cdot f_h = (RR_{sv} + .1 RR_d) V_v f_v \quad (4)$$

The resultant stroke volume relationship is

$$\frac{V_v}{V_h} = \frac{f_h}{f_v} = \frac{RR_{sh}}{(RR_{sv} + .1 RR_d)} \quad (5)$$

(The = symbol was used instead of the approximation symbol  $\approx$ .)

The so-called relative stroke volume,  $V_{\text{vertical}}/V_{\text{horizontal}}$ , was found by using this formula on 500 healthy military personnel of all age groups,

and turned out to be 0.80, with a small variation of  $\pm 0.13$ . This value indicates that stroke volume in the upright position is less than in the horizontal position by approximately 20%. The value is in good agreement with the values obtained by determining blood stroke volume, or by physical circulation analysis. The slight filling of the heart in the vertical position should be ascribed to reduced venous backflow.

#### Evaluation Criteria

An attempt was made, in the physical part, to demonstrate that pulse rate, systolic and diastolic pressures, and blood pressure amplitude change with change in position as compared to the horizontal. The behavior of pulse rate and blood pressure amplitude for 500 military personnel ranging in age from 18 to 56, with the majority in the 20-28 age group, was recorded schematically to show differences in behavior of the individual circulatory factors. Increases in pulse rate were grouped in 15 beats/min steps, and blood pressure amplitudes were grouped similarly, although arbitrarily, for the purpose of demonstrating the many possibilities and to derive a corresponding evaluation for clinical purposes. Table 1 lists the results of this statistical evaluation.

Table 1. Percentage Breakdown of Pulse and Blood Pressure Behavior in the Orthostatic Test of 500 Male Test Subjects

	A	B	C	D	E
1 Pulse rate increase to (beats/min)	15	30	45	over 45	decrease in rate
Pressure amplitude in excess of 30 mm Hg	20.4%	25.8%	3.8%	0.6%	0.6%
2 Pulse rate increase to	15	30	45	over 45	decrease in rate
Pressure amplitude between 15-30 mm Hg	10.6%	17.2%	4.0%	0.8%	0.2%
3 Pulse rate increase to	15	30	45	over 45	
Greater pressure ampli- tude fluctuations to 15 mm Hg	0.4%	0.6%	0.2%	0.2%	
4 Pulse rate increase to	15	30	45	over 45	
Uncharacteristic behavior of syst.pressure, increase in diast. pressure to 20 mm Hg	1.4%	1.2%	0.2%	0.4%	
5 Pulse rate increase to	15	30	45	over 45	
Hypodynamic pressure situation	2.8%	1.8%	0.4%	0.4%	

[Table 1 cont.]

	A	B	C	D	E
6 Pulse rate increase to	15	30	45		
Hypotonic pressure situation	2.2%	1.4%	-		
7 Pulse rate increase to	15	30	45		
Hypertonic blood pressure increase	1.6%	1.0%	-		

Table 1 shows that increases in pulse rate are most frequent up to 15 and 30 beats/min, with blood pressure amplitude ranging between 15-30 mm Hg. All other possibilities occur at lower percentage rates. Accordingly, we compiled the evaluation criteria for pulse rate and blood pressure behavior in a table in order to make rapid, and, for clinical purposes, simple evaluation possible. Classification by groups of orthostatic stability, lability, or orthostatic insufficiency, readily derives from the behavior of individual circulatory factors, although we must admit that this evaluation scale is, in part, based on subjective evaluation criteria. However, these criteria are supported by many years of experience with circulatory function tests (Table 2).

Table 2. Evaluation Criteria for Pulse Rate and Blood Pressure in the Orthostatic Test

1. Balanced behavior of pulse rate and blood pressure in the orthostatic test.
2. Decrease in systolic pressure, increase in diastolic pressure, with blood pressure amplitude in the orthostatic test still adequate
  - (a) with balanced pulse rate behavior;
  - (b) with increased pulse rate.
3. Greater fluctuation in systolic and diastolic pressures, with blood pressure amplitude (decrease in blood pressure amplitude to 15 mm Hg) still adequate
  - (a) with balanced pulse rate behavior;
  - (b) with increased pulse rate.
4. Greater drop in systolic, and rise in diastolic pressure, with decrease in blood pressure amplitude to below 10 mm Hg in the sense of a hypotonic circulatory regulation disorder
  - (a) with balanced pulse rate behavior;
  - (b) with increased pulse rate;
  - (c) with strong pulse rate fluctuations.
5. Drop in systolic and diastolic pressures in the sense of a hypodynamic regulation disorder
  - (a) with balanced pulse rate behavior;



[Table 2 cont.]

- 
- (b) with increased pulse rate;
  - (c) with bradycardic pulse rate.
6. Greater increase in diastolic pressure in the orthostatic test, with balanced systolic pressure behavior
    - (a) with balanced pulse rate (so-called hyperdiastolic pressure behavior);
    - (b) with increased pulse rate.
  7. The examination could not be completed because the patient collapsed.

Evaluation:

Orthostatic stability: 1, 2 a, still 3 a.  
 Orthostatic lability: 2 b, 3 b, 4 a-c, 5 a-c, 6 a, b.  
 Orthostatic insufficiency: 7

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Orthostatic Index

An attempt was made to develop a so-called orthostatic index in order to obtain a more mathematical interpretation of pulse rate and blood pressure behavior, one that could be significant, particularly for statistical evaluations. Evaluation of the circulation situation therefore was not by a semisubjective criterion, as previously, but by a numerical index. An orthostatic index was established in the same way that a performance index was developed in the work test under a constant work load. The following criteria were taken into consideration in setting up the index.

1. The amplitude of the decrease in the systolic pressure ( $RR_s$ ) from the horizontal to the vertical position.
2. The amplitude of the increase in the diastolic pressure ( $RR_d$ ) from the horizontal to the vertical position.
3. The increase in pulse rate ( $f$ ) from the horizontal to the vertical position.
4. Number and amplitude of fluctuations for all three circulatory factors in the vertical position.

These fluctuations can be determined by the variations (6) in these three circulatory factors when compared to the corresponding mean values in the vertical position. The following formula proved to be the most suitable in a number of tests designed to derive a useful formula:

$$OJ = \frac{RR_{sh}}{RR_{sv}} \cdot \frac{RR_{dv}}{RR_{dh}} \cdot \frac{f_v}{f_h} \cdot \frac{1}{3} \sqrt{S_{RR_s}^2 + S_{RR_d}^2 + S_f^2}$$

where

$RR_{sh}$  and  $RR_{sv}$  are the horizontal and vertical systolic pressures;

$RR_{dh}$  and  $RR_{dv}$  are the horizontal and vertical diastolic pressures;

$fh$  and  $fv$  are horizontal and vertical pulse rates;

$s_{RR_s}$ ,  $s_{RR_d}$ ,  $s_f$  are the mathematical variations in  $RR_{sv}$  and  $fv$ .

The orthostatic index should be understood to mean that

1. too great a decrease in systolic pressure in the vertical position, as compared to the horizontal position, increases the first quotient;
2. too great an increase in diastolic pressure in the vertical position, as compared to the horizontal position, increases the second quotient;
3. too great an increase in pulse rate amplitude increases the third quotient; and
4. too great fluctuations in all three factors are expressed as a major increase in the variations. Total variation is calculated mathematically by extracting the square root of the sum of the squares of the individual variations.

Table 3 lists the index values for 500 male test subjects in the 18-56 age group.

Table 3. Orthostatic Index in Percent

Orthostat. Index	2	4	6	8	10	12	14	16	18
Percentage distrib.	0.6	1.2	5.4	17.4	20.6	17.0	12.0	12.0	5.4
Orthostat. Index	20	22	24	26	28	30	32	34	36
Percentage distrib.	2.2	2.2	1.2	1.0	0.6	0.4	—	0.2	0.4

The mean index is 12.4, with a variation of  $\pm 5.1$ . The smaller the index, the more orthostatically stable the test subject. A higher index indicates greater orthostatic lability. However, the index does not include termination of an examination because of orthostatic collapse.

The exact maximum percentage is between indices 8 and 12. Plotting percentages on the y-axis, and indices on the x-axis, yields a distribution approximating that of a "Gaussian curve." Class A 1, or class B 1, corresponds to an orthostatic index of 10, class B 2 to an orthostatic index of 8 to 10, or 10 to 12, etc., if we compare the orthostatic index with the criteria listed in Table 2. Appropriate individual, and 4-area, correlations were calculated to determine the dependence of the orthostatic



index on body height, weight, and age. According to general opinion, for example, "big men" should be particularly labile over a longer standing period, that is, body height and orthostatic index should have a positive correlation coefficient, and the coefficient should be 1.0 in the case of a strictly functional correlation.

However, the results of our correlations showed that a coefficient of  $0.12 \pm 0.04$  (4-area correlation 0.13) is too small to indicate a relationship. The coefficient is absolutely too small, and has a mean error of one third of the coefficient. Correlations of body weight and age also produced coefficients smaller than 0.10, so no correlation could be found for these magnitudes either. On the other hand, the existing, although negligible, relationship between orthostatic index and relative stroke volume is worthy of note. The coefficient is  $0.29 \pm 0.04$ . This relationship indicates that persons with a significantly reduced filling of the ventricle are more labile while standing than persons demonstrating approximately equal ventricle filling while in an upright, or horizontal position.

No relationship exists between orthostatic index and body weight, or between orthostatic index and age. Nor do relationships exist between relative stroke volume and these magnitudes. The coefficients calculated are too small to use to discuss any relationship.

Calculation of the 4-area correlation (a calculation that correlates values found in areas, rather than single values) between the hemostatic height and the relative stroke volume, yielded  $\pm 0.27$ . This relatively good correlation necessarily follows because a lesser static pressure results in a greater filling of the heart when standing.

#### Clinical Significance of the Orthostatic Test

It is evident, in reviewing the percentage breakdown of our findings in Table 1, and the percentage distribution of the orthostatic index, that standard deviation obviously is very great. A high percentage of our findings shows blood pressure amplitudes between 15-30 mm Hg, that is, significant decreases in blood pressure amplitudes caused by greater fluctuations in systolic, as well as diastolic, pressure. Increases in pulse rates up to 30 beats/min, too, are seen in relatively high percentages when a change from the horizontal to the vertical position is made. Schellong, in his "Regulation Test of the Circulation," notes that increases in pulse rate of up to 42 beats/min should not be considered remarkable, but numerous other authors point out that more emphasis should be placed on the relative increase in pulse rate than on the absolute value of the increase (Deliuss, Mechelke).

However, all circulatory factors should be used to evaluate the orthostatic test, because only the interaction of various factors provides an insight into the existing circulation situation. It is our opinion, therefore, that increases in pulse rate exceeding 20-30 beats/min, associated with greater blood pressure fluctuations up to an amplitude of 10 mm Hg, should be taken as a sign of orthostatic lability. A decrease in both blood pressure values, in the sense of a hypodynamic regulatory disorder, and a

lag in blood pressure amplitude to below 5 mm Hg, falls within the concept of orthostatic insufficiency. If we ask ourselves how such changes in pulse and blood pressure curves should be evaluated, the finding must be related to the clinical finding, and to the picture of the disorder, as in any evaluation of a functional test. Interim clinical experience has shown that Schellong's original view, that a hypodynamic form of a regulatory disorder is more frequently seen in hypophyseal cachexia, di-encephalic syndromes, endogenous loss of weight, etc., no longer applies. Even 4.6% of our test subjects, who were almost exclusively members of the Bundeswehr, experienced hypodynamic collapse. Brehm and Wezler rightly pointed out that contradictions are inherent in the hypotonic and hypodynamic relations, because one form does not change into the other, nor should one be regarded as an accelerated form of the other.

Nevertheless, both technical terms can be applied, given the overall concept of orthostatic lability, or insufficiency, to characterize blood pressure behavior.

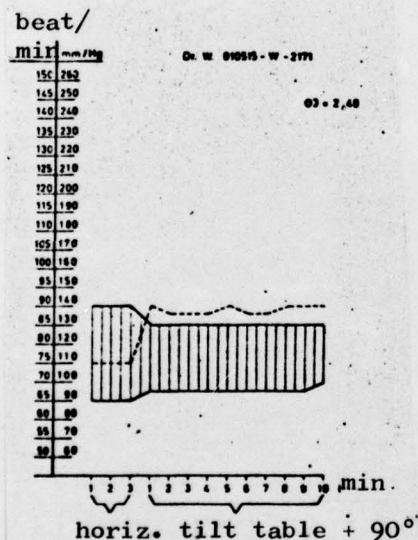


Figure 1. Balanced behavior of pulse rate and blood pressure in the orthostatic test. Orthostatic index 2.48.

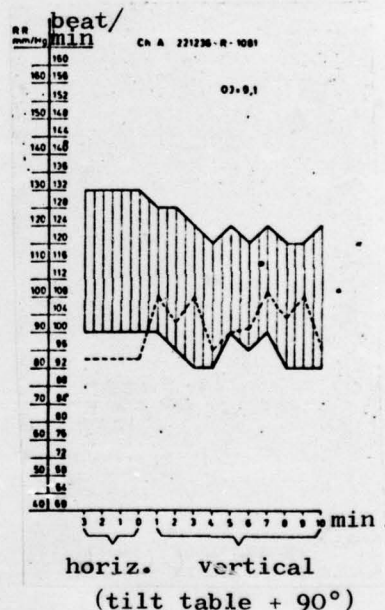


Figure 2. Still balanced behavior of pulse rate and blood pressure in the orthostatic test. Orthostatic index 9.1.

However, one has to guard against too readily relating the pulse rate and blood pressure diagnosis made in the orthostatic test to a specific picture of a disease. It is absolutely impossible to establish such a relationship. The circulation regulation test was made on our test subjects almost exclusively within the framework of an examination for fitness to be a military pilot. The circulation findings made could be related to symptoms of an orthostatic syndrome only in the most rare of cases.

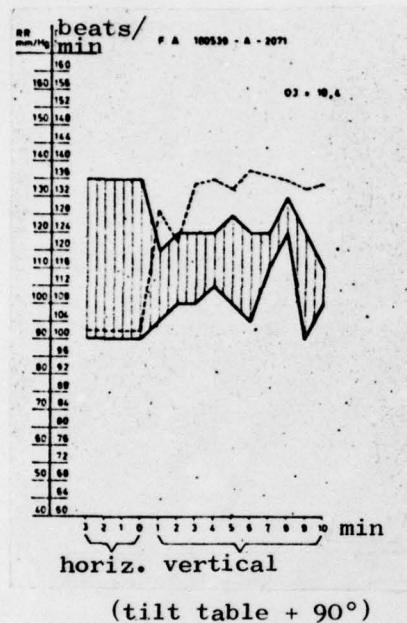


Figure 3. Considerable increase in pulse rate and strong fluctuation in the systolic and diastolic pressures, with decrease in blood pressure amplitude. Findings in the sense of orthostatic lability. Orthostatic index 18.4.

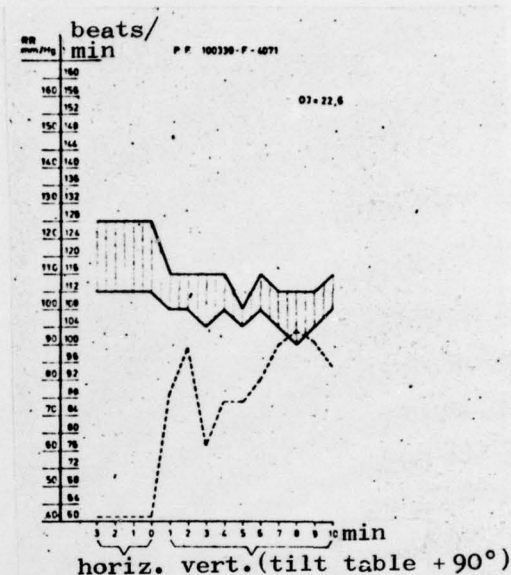


Figure 4. Considerable fluctuation in pulse rate, marked decrease in systolic and diastolic pressures, with decrease in blood pressure amplitude. Findings in the sense of orthostatic lability. Orthostatic index 22.6.

Some clinical symptoms that should be regarded as an indication of orthostatic lability, or orthostatic insufficiency, are a tendency to attacks of dizziness, seeing black, vasomotor headaches, oppressive vertigo, change in face color from pale to red, tendency to heat flashes, reduced drive, becoming tired quickly, great need for sleep, reduced psychic and physical tonus, phases of depression, unproductivity, inability to concentrate, spots dancing before the eyes, unpleasant sensations, nervous yawning. Heart palpitations and stenocardiac disorders also are part of the clinical picture of the orthostatic syndrome.

However, we should be fully aware of the fact, particularly on the basis of our own findings, that evidence of orthostatic lability and, in part, of orthostatic insufficiency, is meaningful for the person affected only when symptoms exist at the same time, and the complaints show a relationship with hemodynamic changes. Such findings must be related to



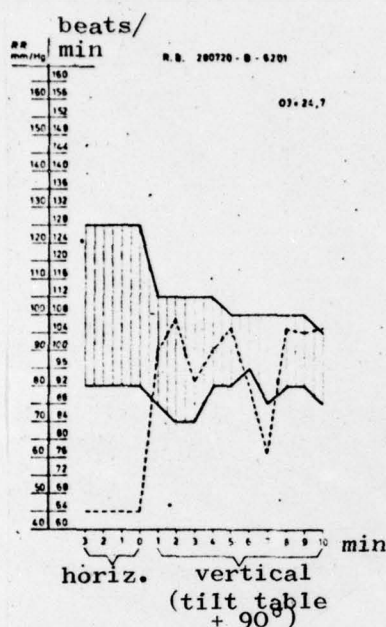


Figure 5. Considerable fluctuation in pulse rate and fluctuations in systolic and diastolic pressures. Finding in the sense of orthostatic lability. Orthostatic index 24.7.

### Summary

Inferences can be drawn as to the stability of the circulation in an experimental subject by observing the values of such circulatory factors as pulse rate ( $f$ ), systolic and diastolic blood pressure ( $RR_s$  and  $RR_d$ ) in the horizontal and in the standing positions respectively. — The typical behaviour of the circulation during experiments in the upright position makes one think of certain physical concepts, which in turn allow certain interesting conclusions about the physiology of the circulation. The rise in diastolic pressure is due to the haemostatics of the blood vessels, a phenomenon which occurs only in the erect posture. The height of the haemostatic pressure was determined; its mean value for 500 subjects was 10 cm. — Another possibility of determining the relative stroke volume, comparing the lying with the upright position, is based on the equivalent bodily performance in either position. — It is also attempted to establish a practical numerical index (OJ), which would indicate the degree of orthostatic stability or lability according to the numerical value. Similar to the performance index, a higher number is indicative of more unfavourable circulatory conditions. The mean index, for 50 subjects, amounted on the average to  $12.4 \pm 5.1$ . — The final part of the study consisted in establishing correlations of the O-indices with body weight, height and age. In not a single case was there any significant correlation. This signifies that there is a general distribution of orthostatic stability or lability which is not related to weight and age.

the personality structure in question and have pathogenic, or pathological, significance only when the clinical finding agrees with the result of the regulation test.

Evidence of orthostatic lability, standing alone, can be evaluated only as a sign of general circulatory lability. A disqualifying judgment should be avoided when evidence of such a finding develops.

An attempt to stabilize the regulatory system should be made, however. This can be achieved by suggesting greater physical activity. Sometimes it may be necessary to assign more active exercise therapy, such as the Ohlstadt treatment, to a person with such orthostatic lability. What must be avoided is to have a finding such as this end up as a clinical orthostatic syndrome. Evidence of orthostatic insufficiency is merely an indication that the person concerned could be prescribed suitable preventive measures.

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